SOME CLIMATOLOGICAL ASPECTS OF ARIDITY IN THEIR APPLICATION TO AUSTRALIA.

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(Seven Text-figures.)

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Introduction.

This paper deals with the question of the climatological factors involved in the concept of aridity, and endeavours to apply these to Australian conditions. In particular, the Index of Aridity as phrased by de Martonne (1927) is examined in detail for annual conditions in Australia, and the idea extended to a survey of the monthly conditions. So far as the authors are aware, none of these, except generalized versions of Figures 1 and 2, has appeared before. In addition to considering the characteristic appearance of drainage systems, the map and data have been critically examined with reference to agricultural facts. The authors believe that an attempt should be made to define the nature of aridity, however complex this may be.

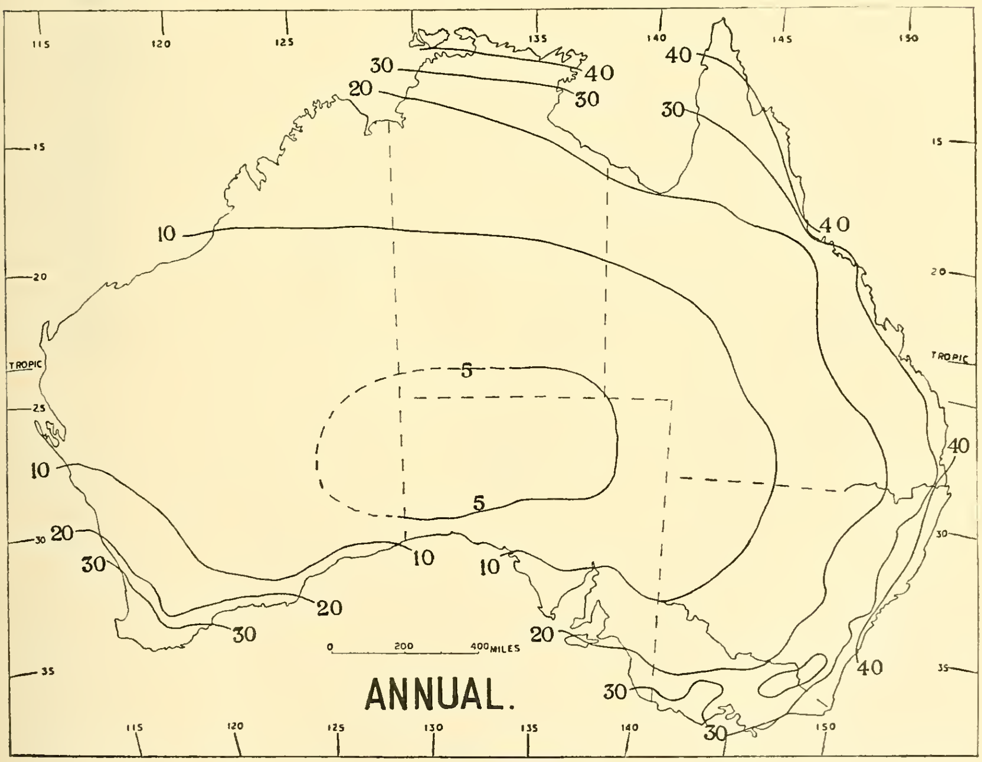

Fig. 1.—The index of aridity for mean annual conditions in Australia. The more arid the region the lower is the index figure.

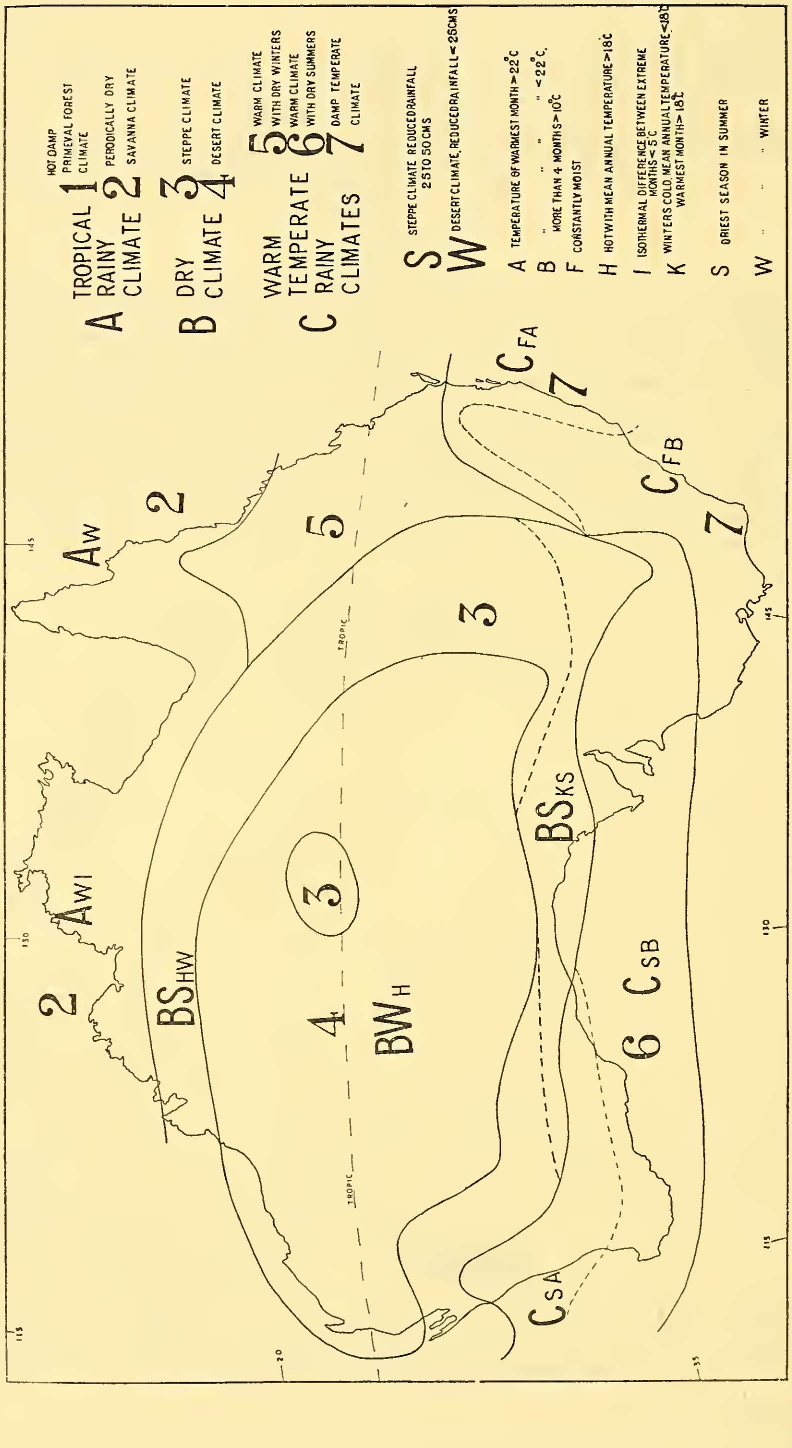

Fig. 2.—Koppen's climatic zones in Australia.

Definitions of Aridity.

Although many writers have discussed arid lands, most have been content to apply the terms "desert", "arid", "semi-arid", etc., without definitions. The popular acceptance of the underlying idea has been so complete as to make more explicit statements unnecessary in non-scientific works. Within the last few decades, however, when attention became focussed on scientific climatology, attempts have been made to define the nature of aridity.

These attempts fall into two classes: firstly, those with an empirical basis and, secondly, numerical definitions which have been made for the purpose of illustrating climate distributions of continental dimensions. Of the former some of the more important are as follows:

> "A desert is a region of sparse and specialized plant and animal life" (Isaiah Bowman);
>
> "A desert is a region with a rainfall of 10 ins. or less per annum, where agriculture is impracticable, and where occupation is found possible only for a sparse population of pastoralists" (J. W. Gregory);
>
> "A desert is a region of small rainfall (sometimes, however, amounting to 16 ins. per annum in a hot region) with a sparse and specialized plant and animal life. It is not found capable of utilization by stationary pastoralists even after the borders have been occupied by this class for 50 years" (Griffith Taylor).

These definitions of course leave room for very considerable variation in the drawing of boundary lines.

Among the numerical definitions of the second class may be mentioned that of Mark Jefferson (1916), where he states that in the United States less than 5 inches per annum gives desertic conditions; from 5 to 10 inches gives arid conditions, and from 10 to 20 inches gives semi-arid conditions. Koppen (1923) gives 25 cm. (10 in.) as indicative of the desert boundary, and 25 to 50 cm. (10 to 20 in.) as indicating "steppe" conditions. De Martonne also recognizes 25 cm. as significant in the delimitation of desert climates.

These estimates are first approximations, and must be studied in their local applications. Russell (1931) has recently modified Koppen's formulae in their application to dry regions of the United States as a result of field examination of his climatic boundaries.

Criteria available.

Several points of reference may be made in defining "aridity", e.g., climatological, physiographic, vegetational, or developmental and occupational. It is assumed in this paper that a complete definition of aridity must contain reference to each of these. From our present point of view, however, there are some considerable difficulties in the way of using any of them for purposes of definition. The stations taking complete records even of precipitation and temperature alone are very few in relevant regions in Australia. Again, there is no adequate basis so far proposed that will enable one to compare in a quantitative manner landscapes in various regions. Few studies, too, with notable exceptions in South Australia, have been made of the ecology of dry regions. Our data are obviously incomplete, and must be accepted as inevitably so.

In the present study attention has been almost exclusively focussed on the climatological aspects of the problem, and we have immediately to decide which factors of climate are available for correlation. There is no doubt that a full and detailed examination of climatic conditions at any point or points should include as many of the so-called climatic factors as possible, viz., precipitation, temperature, evaporation, humidity, wind, atmospheric pressure, and so on. Such data are actually available for the capital cities of Australia, as well as for a very small number of other stations, but from the nature of the case we can expect only very sparse and most generalized data from the little-inhabited dry regions of the continent. Indeed, we might say that for the greater portion of Australia there are available only records of precipitation and temperature, the latter being given as a twenty-four-hourly mean which is obtained from the mean of the 9 a.m. and the 3 p.m. readings. In the dry areas the stations are scattered, while one large region in the central west has no permanent stations.

Maps of relative humidity (Taylor, 1916), evaporation (Hunt, 1914) and saturation deficit (Prescott, 1931*b*) have been published. When considering these, particularly with reference to the climatic ratios described later, the authors came to the conclusion that in view of the conditions described above, there was a considerable element of danger in the use of any of them for the purposes of defining the nature and extent of aridity. As regards the first of these maps, mean annual relative humidity figures, or even, if such were available, daily mean figures are of little importance if we do not know the variations which occur throughout the day, and which have been shown to be very important factors in the growth of certain plants in arid regions. As regards the map showing evaporation, there is now a considerable body of opinion opposed to the use of evaporimeter readings, as the conditions governing the evaporation of water in an open dish are very different from those governing the evaporation of water from the soil in the same area. We still have no generally accepted method that can be applied to continental areas of determining the rate at which water is evaporated out of the soil, a vitally important matter in regions where duricrust products are so abundant and where vegetation generally is so dependent on the presence of water supplies in the soil and subsoil. In the case of the third of these maps, the concept of saturation deficit is still a comparatively new one, and as regards Australia the values on which the map was constructed had, with the exception of a small number of stations, to be calculated from the mean temperature and relative humidity data. In the first place the objections previously stated in regard to relative humidity figures hold here too, while in the second place there is still doubt as to the relations between saturation deficit and evaporation in arid regions.

It has seemed advisable, then, to work with the first-hand data that are available and to confine ourselves to precipitation and temperature and their seasonal incidence. It should be noted that in so doing we are following the lines laid down by two climatologists who have worked on the continental scale, namely Koppen (1923) and de Martonne (1927). As is shown later, much of de Martonne's work is adopted for the present paper, though it is amplified by considering monthly conditions and by introducing the concept of the arid period and its duration.

Index of Aridity.

In an attempt to give a numerical value to the *intensity* of arid conditions. several climatic ratios must come under review. Some of these ratios were devised for quite other purposes than the present one, and are not at all suitable for use in arid regions. The most important are:

1. *Transeau Ratio.*—This ratio may be expressed as $\frac{P}{E}$, the relation of annual precipitation (P) to annual evaporation (E). It was thought that this would give an index of effectiveness of precipitation chiefly as regards plant life, but it is obvious that for States involving areas of continental size the value of the ratio is diminished by the small number of stations taking evaporation readings. In Australia there are available only some 23 stations with published evaporation figures, and these are mainly outside the arid regions. Also, five of them are situated on the coastline.

2. *Thornthwaite Ratio.*—In a recent study of the climates of North America, C. W. Thornthwaite (1931) faced the same difficulty, and devised an empirical method whereby the $\frac{P}{E}$ quotient may be computed from the mean monthly temperatures and the mean monthly precipitation. The method is as follows: The quotient $\frac{P}{E}$ is considered the precipitation effectiveness ratio of a single month, and the $\frac{P}{E}$ index is the sum of the twelve monthly $\frac{P}{E}$ ratios.

$$I = \frac{P}{E} \text{ index},$$

$$I = \sum_{n=1}^{12} 10\left[\frac{P}{E}\right]_n$$

$$= \sum_{n=1}^{n=12} 115\left[\frac{P}{T-10}\right]_n^{\frac{10}{9}}$$

T in degrees F., and P in inches. To avoid the inconvenience of dealing with fractions, each quotient has been multiplied by ten, so that the precipitation effectiveness index is ten times the sum of the twelve monthly $\frac{P}{E}$ ratios. It is clear that this $\frac{P}{E}$ index is not the same as Transeau's, which is the relation of annual precipitation to annual evaporation. This equation is checked by reference to the fairly large number of stations taking evaporation figures in North America, but at the same time it must be remembered that this apparently precise method of determination may very possibly have little basis in reality. In arid regions in particular, there are no means of checking the relations which are assumed between precipitation, temperature and evaporation. For all essential purposes, Thornthwaite's ratio must be regarded as an attempt to carry further the Transeau ratio, and as a method which, while apparently giving approximately correct results when applied to North America, could obviously not be extended *in toto* to areas in which primary figures are much less satisfactory.

3. *Meyer Ratio.*—The Meyer ratio, $\frac{P}{s.d.}$, is the relation between the precipitation in inches or centimetres, and the atmospheric water vapour saturation deficit, also measured in inches or centimetres. Even more than the Transeau ratio this can only be applied to those very rare stations which take measurements of these factors, and thus can probably be applied to no large continental areas. However more exact may be the measurement of the saturation deficit as an index of precipitation efficiency than is the measurement of evaporation, it is at present impossible to argue with any degree of assurance concerning conditions in arid regions.

4. In recent studies of the soils of Australia J. A. Prescott (1931*a*, 1931*b*) has used the Meyer ratio and produced maps of atmospheric saturation deficit for Australia. The saturation deficit has been calculated from the relationship between the mean annual temperature and relative humidity. The mean evaporation in inches is said to be related to the saturation deficit in inches of mercury as E = 263 s.d., this figure having been obtained by the correlation of 23 stations. By means of these figures the Meyer ratio and the Transeau ratio are considered as being more or less interchangeable. The present authors consider, however, that a map constructed on this basis and with these data can only be so highly schematic as to have little value for the purpose of the delimitation of climatic boundaries. Relative humidity figures themselves are scarce, and the determination of saturation deficit by means of these can only be obtained for a number of stations and in certain localities. On the other hand, it should be pointed out that the precision given to the relation between saturation deficit and evaporation is in all probability more apparent than real. It is particularly questionable when applied to tropical and central portions of the continent, since stations available for the correlation are few in number and are to be found only in southern Australia.

5. *Lang Factor.*—The Lang factor, $\frac{P}{T}$, is the quotient of annual precipitation in millimetres divided by the mean annual temperature in degrees centigrade. This factor has been criticized, firstly because it assumes a constant ratio between precipitation and evaporation, secondly because it considers only these two factors, P and T. As regards the first objection, it is true that this simple relationship does not obtain over a wide range of climatic conditions, while as regards the second, the paucity of our information concerning evaporation, saturation deficit and so on is at least as great as our ignorance of wind and other factors, particularly in arid regions.

6. A further index has been devised by de Martonne, which is in effect an extension of the Lang ratio. This is to be expressed as $\frac{P}{T+10}$, where the precipitation in millimetres is related to temperature in degrees centigrade. The introduction of the constant in effect obviates some of the anomalies resulting from the use of the Lang factor. It is probable that a more detailed use of de Martonne's ratio would help towards the reconsideration of the value of the constant, but at present, on the basis of physiographic grounds, the constant is accepted as fixed. Important features concerning this index are as follows:

(*a*) It makes use of the only reliable climatic data which are available for that part of the continent. The relation it expresses is simple and yet fundamental, and may be modified by the introduction of other factors as our knowledge increases. Empirically, the ratio has been tested for all the continents of the world, and has been found to agree well with physiographic indications of climatic regimes.

(*b*) Significant index numbers.—De Martonne considers the significant values to be as follows: Indices below 5 characterize true deserts; indices about 10 more or less correspond with prairies; about 30, forest vegetation tends to predominate, and gains complete control of the soil where the index exceeds 40, provided the temperatures are not too low. In the same way no cultivation is possible without irrigation where the index is below 10. Between 10 and 20 is the domain of dry farming. (Compare these with Fig. 1.)

(*c*) While allowance is made in the formula for the varying relations between effectiveness of precipitation and the temperature, the factor of seasonal concentration of precipitation does not receive adequate attention if mean annual conditions alone are considered.

The Intensity of Aridity.

Examination of the intensity of arid conditions is the first step in defining the nature of aridity. Using de Martonne's index a series of maps of this nature were constructed. Fig. 1 shows the annual conditions.

*The Map of Annual Conditions.**

Features that may be observed are:

1. In general arrangement and pattern the lines of equal aridity resemble the arrangement of the annual isohyets, i.e., they are (*a*) concentric with the central regions of the continent; and (*b*) the index numbers increase towards the coasts, i.e., aridity decreases.
2. There are some interesting divergences from the above general impression: Aridity isolines which coincided with isohyets in southern Australia lie considerably further to the north of the same isohyets in tropical Australia; so that the introduction of the T factor has enlarged the arid boundary in tropic areas which were not classed as arid solely by consideration of the P factor.
3. There is little differentiation in the central regions. This is mainly due to the small number of stations maintained therein; the figures available show variations that suggest fairly complex conditions.
4. There are two areas of very high values, both situated in the eastern portion of the continent. The first and more extensive of these is on the North Queensland coast in the vicinity of Cairns. Here values reaching up to 109 (Innisfail) may be obtained, these being mainly the consequence of very high rainfalls experienced along this littoral. The second region is the Monaro and the Australian Alps, where fairly high rainfalls are combined with low highland temperatures.
5. There are some interesting correlations to be made with various other distributions. The isoline of ten includes practically all the country in Prescott's vegetation map marked as desert sandhill and as acacia semi-desert, and also some of the mallee and sclerophyll woodlands. Rain forest is found only where the index rises to 40, and where temperatures are high. In regions of similar index (40) and low temperatures, as in Monaro, mountain grassland and moor are to be found. The regions between 10 and 20 which are situated north of the tropic include most of the savanna country of the continent, and similar regions in southern Australia are occupied by mallee and by sclerophyll scrub and woodland. Unfortunately, it is not possible to distinguish accurately de Martonne's true desert areas which have an index of less than 5, though their eastern borders are indicated. There is therefore no differentiation in our map

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* This map and the maps of monthly conditions have been drawn with the aid of numerous rainfall and temperature statistics supplied through the courtesy of the Commonwealth Meteorologist, Mr. W. S. Watt.

corresponding to the differences between sandhill desert and Prescott's acacia semi-desert and shrub steppe. As regards the agricultural distributions, it will be seen that the main wheatlands of the continent lie in the regions with index 12 to 30, and that there is no agriculture under natural conditions in regions with index lower than 10. Tropical agriculture is only to be found in those regions with an index of more than 35.

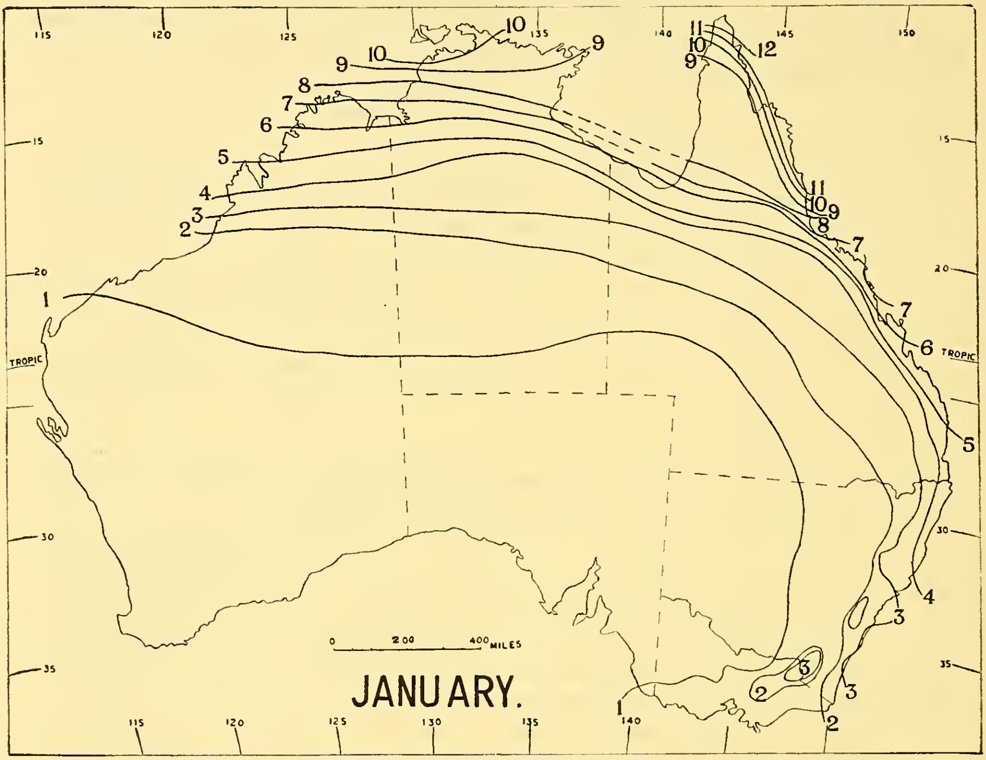

Fig. 3.—Index of aridity for January. The lower the index figure the more intense is the aridity. The isoline of index 1 is significant in distinguishing the arid border.

6. The relations of aridity isolines and the nature of the drainage system may be summarized as follows: It is not possible to give a numerical value to the boundary between areic and endoreic areas.* The boundary between endoreic and exoreic regions, however, may be drawn with considerable accuracy. This will be found to coincide fairly closely with the isoline 10, except on the north-west coast from Shark Bay to Port Hedland, where several occasionally flowing streams such as the Ashburton and the Gascoyne have their channels emptying to the Indian Ocean.

* These terms were proposed by de Martonne. Regions of areism are those with no run-off of precipitation; of endoreism, those of interior-basin drainage; of exoreism, those drained by streams flowing to the oceans.

The annual map, then, gives a general impression of the conditions which agrees well with other observed facts. At this stage it is interesting to compare the regions indicated as arid in this map with the arid regions shown in Koppen's map of the continent (Koppen, 1923). It will be seen from Fig. 2 that Koppen's diagram divides the central regions into "desert" (BWh, desert climate, reduced rainfall less than 25 cm., mean annual temperature greater than 18° C.), and "steppe" (BShw, steppe climate, reduced rainfall 25 to 50 cm., hot, with mean annual temperature greater than 18° C., dry season winter; and BSks, steppe climate, reduced rainfall 25 to 50 cm., winters cold, mean annual temperature less than 18° C., warmest month greater than 18° C., driest season in summer). The southern boundary of Koppen's "steppe" regions coincides fairly exactly with the

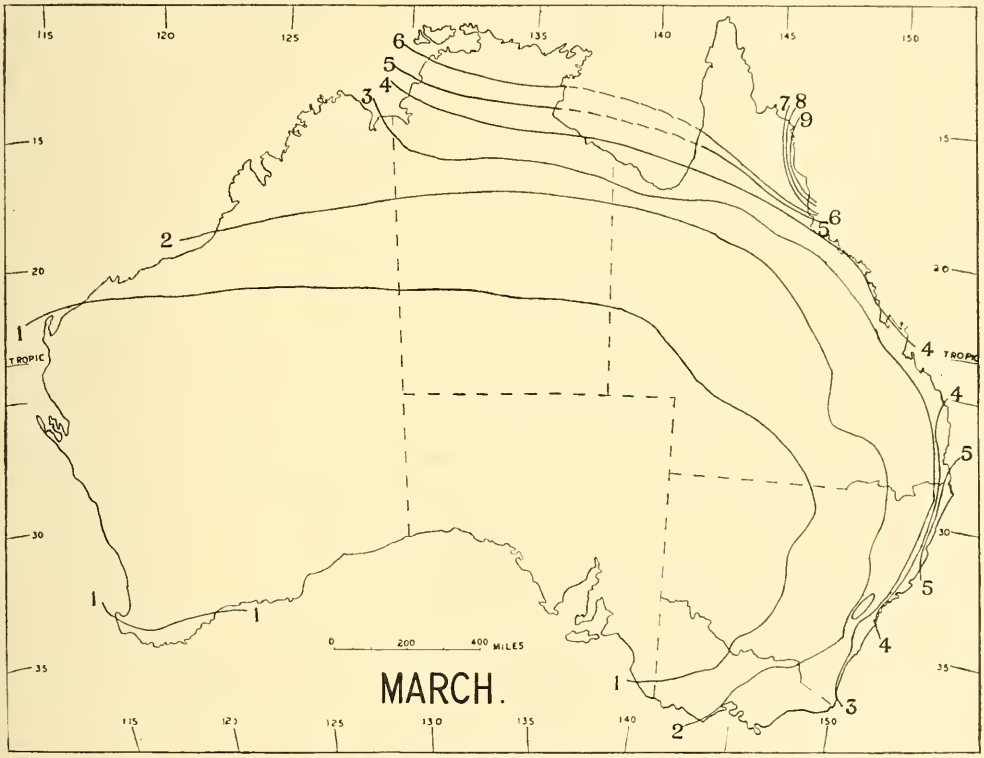

Fig. 4.—Index of aridity for March.

aridity isoline of index 10 (Fig. 1), but in the tropical north the latter is rather coincident with the "desert" boundary of Koppen. In other words, Koppen sees steppe conditions extending further north in the tropics. This same tropical region of the South Kimberleys appears in Prescott's vegetation map of Australia (Prescott, 1931) as "savanna woodland" mixed with "savanna and Mitchell grass downs". The region is drained by the Fitzroy and the Ord, which both have well defined channels. The disharmony results from considering annual summations alone in a region with very strongly marked seasonal characteristics.

The annual map must necessarily, however, be a generalization, as monthly conditions vary very considerably in different parts of the continent. It is essential to a full understanding of the nature of aridity that monthly conditions should be analysed. A series of monthly maps using the same formula was constructed and those for January, March, June and October were selected as typical of the seasonal conditions. The most important features of these may be summarized as follows:

1. During *January* (Fig. 3) the most arid portions of the continent are to be found in the south-west and central southern areas. High indices representing heavy summer rainfalls can be found through most of northern Australia, and extending down the east coast. The gradient is very steep inwards both from the north and east coast as distinguished from the very gentle gradient of the dry area. In tropical Australia, the isolines

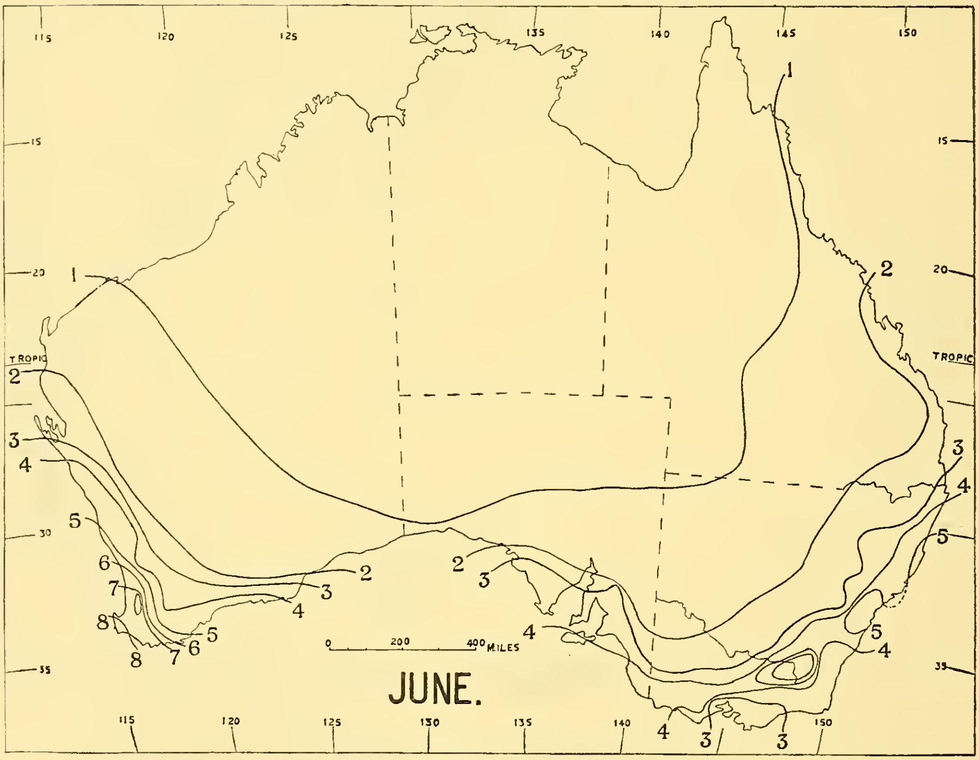

Fig. 5.—Index of aridity for June.

run east and west with only slight irregularities until the east coast is approached. During this month there is practically no agriculture within the isoline 1. South-west portions of the continent are under prolonged summer drought. This applies also in rather less degree to the wheatlands of South Australia, north-west Victoria and the plains of New South Wales.

2. Conditions in *March* (Fig. 4) show considerable similarity. The isoline 1 has moved westward from the Riverina, but the arid areas are increased in the centre of the continent, where the autumn rains are very sparse.

The extreme south-west portions of the continent are now receiving their first winter rains. In the tropical and east coast areas the gradient is very much less, though almost identical values are received in the Cairns section as were received in January. As regards agriculture in southern Australia, the commencement of the wheat sowing season is marked by the westward retreat of the isoline 1. In south-western Australia, on the other hand, where rather later sowing rains are desirable, summer droughts are still in force.

3. The *June* map (Fig. 5) shows a complete reversal of the January conditions. The arid portions of the continent are now north and north-west, with the east coast and the south of Australia receiving their winter rainfalls. The agricultural lands of the south are now showing indices of over 2, and the

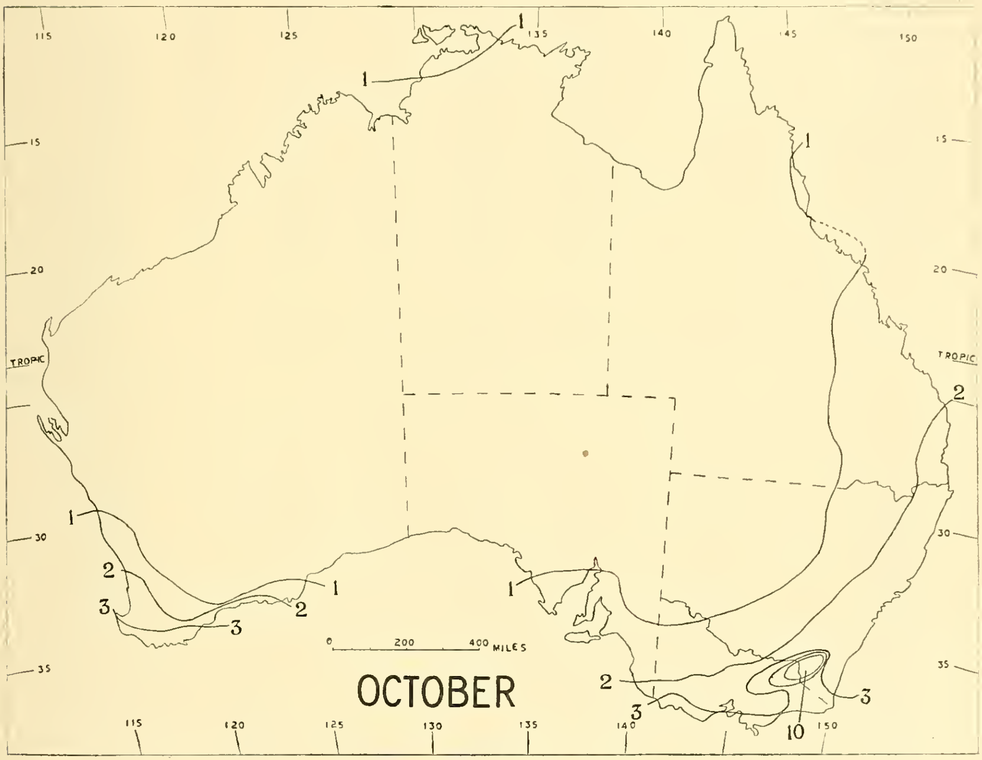

Fig. 6.—Index of aridity for October.

wettest portions are the southern littorals. It is worth noting that this arid area in the winter month is considerably more extensive than is the arid area shown in the January map.

4. For *October* (Fig. 6) the chart shows extensive location of arid conditions as far as northern and central Australia is concerned. The agricultural lands of the east coast and the Murray-Darling basin alone in the east show higher indices than 1, while in the whole of the western half of the continent only Swanland has similar values. This month is agriculturally important in the determination of the ultimate yield of the wheat

crops, and climatic conditions at this period are extremely important in influencing the extension of wheat crop areas. On the extreme north coast, centring round Darwin, the "Wet" is beginning to appear, and Darwin shows a value of 1·3.

TABLE I.—*Indices for Important Stations.*

	January.			March.		
	P	T	I	P	T	I
Sydney	91·4	21·9	2·90	126·0	20·7	4·10
Melbourne	47·8	19·6	1·61	57·1	18·1	2·03
Brisbane	165·0	25·1	4·70	148·0	23·5	4·40
Perth	8·6	23·2	0·26	19·8	21·8	0·62
Adelaide	18·0	23·2	0·54	25·6	21·0	0·86
Darwin	398·8	28·8	1·01	253·0	28·9	6·50
Broome	160·6	29·7	4·05	89·4	29·6	2·25
Alice Springs	43·4	28·4	1·14	31·2	24·8	0·90
Camooweal	98·6	30·4	2·45	53·6	28·1	1·40
Broken Hill	17·2	25·6	0·48	16·0	22·1	0·50
Wiluna	34·8	29·8	0·87	32·0	26·6	0·87
Hall's Creek	147·0	30·3	3·64	77·2	28·2	2·02
Albury	38·6	24·3	1·13	49·9	20·6	1·63
Tarcoola	8·4	24·7	0·24	12·2	23·3	0·36
Daly Waters	162·6	30·5	4·00	120·9	28·7	3·12

TABLE I.—*Indices for Important Stations.*—Continued.

	June.			October.			Year.		
	P	T	I	P	T	I	P	T	I
Sydney	123·1	12·6	5·40	73·9	17·6	2·67	1,206	17·3	44·4
Melbourne	52·3	10·2	2·60	66·0	14·3	2·70	648	14·7	26·1
Brisbane	71·6	15·7	2·78	64·3	21·0	2·07	1,157	20·5	38·0
Perth	178·5	13·7	7·50	54·7	16·0	2·10	883	17·9	31·6
Adelaide	79·2	11·9	3·60	43·7	16·7	1·64	536	17·2	19·6
Darwin	3·0	25·9	0·08	51·8	29·6	1·30	1,531	28·2	40·0
Broome	24·4	21·8	0·77	0·7	27·2	0·02	590	26·5	16·2
Alice Springs ..	14·7	12·4	0·65	18·8	23·0	0·57	272	20·9	8·8
Camooweal ..	9·4	17·9	0·32	13·9	27·3	0·37	385	24·9	11·1
Broken Hill ..	30·2	10·7	1·45	20·3	18·7	0·71	244	18·1	8·6
Wiluna	25·4	12·9	1·11	6·3	21·4	0·20	250	21·4	7·9
Hall's Creek ..	4·5	18·7	1·60	15·2	28·6	0·39	524	25·5	14·8
Albury	85·5	8·9	4·51	65·8	15·7	2·60	692	16·0	26·6
Tarcoola	22·1	10·9	1·60	17·8	18·6	0·62	177	18·4	6·2
Daly Waters ..	6·3	21·3	0·20	21·3	30·1	0·53	670	26·8	18·2

5. The arid border is a zone which fluctuates from month to month. In bad seasons it may extend into whole divisions of any of the States and signalize crop failure. In good seasons the wheatlands flourish, and far into the interior grass and water are abundant. The defining of this zone will be partly a matter for field work, but it can be partly defined by our existing knowledge. From careful examination of the statistics, supple-

mented by our knowledge of the behaviour of some crops under certain climatic conditions, a tentative selection of the index 1 was made as the arid boundary. Knowledge of the distribution of wheat cultivation and the growth of wheat under certain climatic conditions is very useful, for wheat is the most widely-spread and one of the most uniformly cultivated of our crops. (See Table II for representative occurrences of the index 1.)

TABLE II.—*Some Representative Stations Showing P and T Values, which give a Monthly Index of 1.*

Station.	Lat. S.	Index.	Month in which that Index Occurs.	T in that Month.		P in that Month.	
				F°	C°	in.	mm.
N.S.W.—							
Bourke	30·5	1·00	May	59·8	15·5	1·01	25·6
,, ...		1·05	Feb.	83·0	28·3	1·59	40·4
,, ...		0·92	Dec.	82·3	28·0	1·37	34·8
Broken Hill ..	31·58	0·99	Aug.	52·9	11·6	0·84	21·3
,, ..		1·02	May	56·6	13·7	0·97	24·6
Forbes	33·25	1·10	Feb.	77·6	25·4	1·54	39·1
Hay	34·35	1·00	Apr.	62·9	17·1	1·08	27·4
Quambone	30·31	0·99	Jan.	80·7	27·0	1·45	36·8
Walgett	30·1	1·00	Oct.	69·4	20·7	1·21	30·7
Nyngan	31·34	0·96	Sep.	58·6	14·8	0·94	23·9
Victoria—							
Mildura	34·13	0·94	Oct.	63·4	17·4	1·02	25·9
Charlton	36·16	0·98	Mar.	66·5	19·2	1·17	29·7
Bendigo	36·46	0·96	Feb.	71·3	21·8	1·21	30·7
South Australia—							
Adelaide	34·57	0·98	Nov.	67·0	19·4	1·14	28·9
Port Pirie	33·1	0·96	Apr.	67·2	19·5	1·12	28·4
Queensland—							
Thursday Island ..	10·33	0·96	Nov.	82·7	28·2	1·45	36·8
Townsville	19·10	0·97	May	75·3	24·1	1·30	33·0
Windorah	25·25	0·97	Dec.	85·4	29·6	1·51	38·3
Charleville	26·55	0·97	Oct.	72·4	22·4	1·24	31·5
Bollon	28·0	0·99	Oct.	70·7	21·5	1·23	31·2
Western Australia—							
York	31·53	1·00	Oct.	59·8	15·5	1·01	25·6
Kalgoorlie	30·45	0·97	July	52·4	11·3	0·82	20·8
Hall's Creek.. ..	18·16	0·95	Nov.	87·1	30·7	1·52	38·6
Derby	17·19	1·05	Apr.	83·5	28·6	1·60	40·6
Marble Bar ..	21·6	0·99	June	67·7	19·8	1·16	29·4
Central Australia—							
Alice Springs ..	23·42	1·02	Feb.	82·2	27·9	1·52	38·6

The Duration of the Arid Period.

Having made a selection of the aridity index 1 as a significant indication of the extension of arid conditions, Figure 7 was plotted so as to show the number of months through the year which in average years would be classed as arid. This brings us to the consideration of the *duration* of the arid period and its position in the year, a point which we regard as of primary importance. The general features of the map may be summarized as follows:

1. There is an area in the central southern portions of the continent which has practically continuous arid conditions. This extends from the south-

western portions of Queensland, through the northern portion of South Australia to the Western Australian boundary. Its westward extension from this line cannot be precisely determined because of the absence of meteorological stations, but it is probable that the central portions of Western Australia (i.e., a high proportion of the area containing sand ridges) come within its boundary.

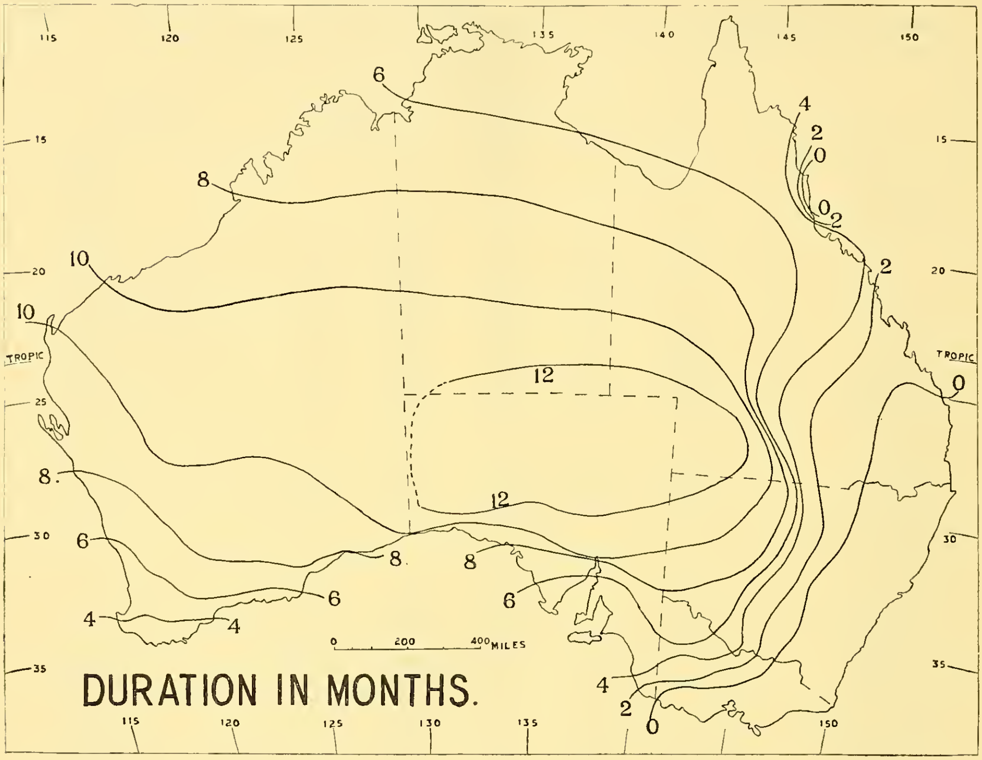

Fig. 7.—The mean duration of the arid period, in months. Regions with an index of 12 have practically permanent aridity; those with an index of 0 are rarely arid for any months. The index of 8 is suggested as significant in the definition of the arid border.

2. There is an extremely steep gradient in eastern Australia, and particularly in south Queensland, between the extremely arid and the humid areas. It is to be interpreted in the first place as indicating a marked and sudden change in arid conditions which should be reflected to some comparable extent in landscape and vegetation distributions. In the second place it will be obvious that in these regions deviations from the average conditions will produce very marked effects due to the close propinquity of arid and humid regimes.
3. The regions in which arid conditions do not exist in average years are limited to areas in which precipitation is fairly evenly distributed through the year. These regions are confined to eastern Australia. The most favourably placed areas are indicated as being south-eastern Queensland, and New South Wales and Victoria to the east of the highlands and

western slopes. A small isolated area of similar characteristics is to be found on the north Queensland coast in the vicinity of Cairns.

4. Interesting conditions are to be observed in south-western Australia. Here there are at least four months of arid conditions. These dry periods, which occur mainly in summer and spring, inhibit growth for the time being, but have not prevented the development of extensive forests and woodlands.
5. Tropical Australia shows, with the exception of the Queensland coast, comparatively little range in arid conditions. The dry period ranges in length from five to ten months, but the greater portion is less than eight months.
6. As an indication of the arid border, considerable reliance is to be placed upon the isoline of 8. This coincides well with the extent of desert and semi-desert vegetation associations; includes the area having endoreic drainage; and there is included within it no lands in which agriculture has proved successful, though it comes close to the dry border of the important wheatlands.
7. As compared with the map showing the intensity of the annual conditions (Fig. 1), this duration map provides a much more satisfactory summary. Since aridity means the temporary suspension of many biological and geomorphological processes of fluvial regions, then an important question is the average length of the period which elapses before these are resumed. Thus from the biogeographical viewpoint, the most important aspect of arid climates is that the arid period is relatively very long and not that it is relatively dry. Other climates (such as tropical climates which have a dry season, or that group of climates resembling more or less closely the Mediterranean type) also have an arid period which, however, in average years is not long enough to result in the establishment of true arid plant and landscape types.
8. It follows from what we have said that there is a *critical length* of the arid period. Regions where a dry period longer than this critical length recurs frequently are desert-like, though an occasional retreat of the arid border means a brief time of luxuriantly growing annuals and flowing stream channels. On the other hand, regions which usually lie on the wetter side of the arid border sometimes experience years when the arid period stretches beyond the critical stage, and drought takes possession of the land. In the central west of New South Wales one may see areas of dead pine which were killed in the 1902 drought. Drought is, after all, a relative term, and is applied to dry periods which last longer than is normal.
9. The final point to be made here deals with the frequency of the occurrence of the critical length. Every climatic type represented in Australia has an arid period of greater or less length. What marks out large areas of the interior from the other regions is the greater intensity, duration and frequency of the arid period. The question of frequency will lead us to the consideration of actual instead of average years, but we know that in these regions it is frequent enough to result in the establishment of certain recognizable types of landscape and vegetation. One of the major problems that confronts us is concerned with the relation of the intensity and frequency of the arid period and the cumulative effect on the natural landscape of very frequent arid periods of more than critical length.

Conclusion.

The present-day climatic factor is the most important of the immediate causes of aridity. The dominant climatic character in arid regions is the length of the period in which most geomorphological and biological processes of fluvial regions are suspended or greatly curtailed because of the absence of an effective precipitation. Definite limiting values are suggested for the efficiency of precipitation (in monthly means) and for the critical length of the arid period. The authors suggest, as a basis for discussion, the definition that regions of aridity are regions of markedly intermittent and strongly contrasted geomorphological and biological processes which are controlled in their occurrence by the length of the period of insufficient precipitation; these arid periods are of such length and recur so frequently that the processes associated with them are dominant in determining the cultural and natural landscapes.

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